Renewable and Sustainable Energy Reviews 38 (2014) 811–820

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Can solar panels leapfrog power grids? The World Bank experience 1992–2009☆

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ARTICLE INFO

Article history:
Received 10 February 2014
Received in revised form
9 May 2014
Accepted 6 July 2014
Available online 24 July 2014

Keywords:
Solar photovoltaic
Off-grid solar home system
Greenhouse gas emissions

ABSTRACT

Solar photovoltaic systems promise both rural access to electricity and reduction in greenhouse gas emissions. During 1992–2009, the World Bank contributed US$790 million to promote the uptake of off-grid solar home systems in 34 developing countries. This paper reviews the experience of the World Bank involvement in the rural solar photovoltaic market and draws lessons learned. The review finds that World Bank efforts, using quality-contingent producer subsidies and relying on microfinance for consumers, have been effective in stimulating the diffusion of the solar technology although the impact on greenhouse gas reductions is rather limited because of limited energy consumption of off-grid households.

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☆I thank Kenneth M. Chomitz and participants at the American Evaluation Association's annual conference for helpful comments on earlier drafts. An earlier version of the paper has served as a background study for World Bank Independent Evaluation Group (IEG)'s Climate Change Phase II Evaluation: the Challenge of Low-Carbon Development Climate Change the World Bank Group. I appreciate IEG's support for the study. The findings, interpretations, and conclusions expressed in this paper are entirely those of the author. They do not necessarily represent the views of the International Bank for Reconstruction and Development/World Bank and its affiliated organizations, or those of the Executive Directors of the World Bank or the governments they represent.

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http://dx.doi.org/10.1016/j.rser.2014.07.047
1364-0321/

1. Introduction

About one and half-billion people in the world are living without electricity, among which four out of five are in remote villages in the developing world [1,2]. In areas where it is prohibitive to extend electrical grids – because of low population densities, long distances from the existing grid, and difficult terrain – off-gird solar photovoltaic (PV) technologies cam provide a cost effective alternative to bring light and power to the rural poor.

Solar PV technology converts sunlight directly into electricity without any heat engine to interfere. PV devices offer several advantages: they are simple in design, requiring very little maintenance, emitting zero greenhouse gases, and suitable for being constructed as stand-alone systems to give outputs from microwatts to megawatts [3]. In the past decades, a stand-alone solar PV system, also called a solar home system (SHS) has received a great deal of attention for efforts to electrify off-grid rural areas. A SHS typically consists of a PV module, a rechargeable battery, a charge controller, wiring, fluorescent direct current lights, an inverter and outlets for other DC appliances (such as radio and TV). The SHSs are rated in peak kilowatts (kWp) which is an amount of electrical power that a system is expected to deliver when the sun is directly overhead on a clear day [4].

Without power, rural communities usually rely on environmentally unfriendly energy sources, such as kerosene for lighting. A shift to solar power not only provides higher quality lighting, but also promises to reduce indoor air pollution and carbon emissions. Studies analyzing the economics of stand-alone PV power system have shown that the life cycle cost of PV energy is lower than the cost of energy from diesel or petrol generators and that the solar PV system is economically feasible in remote and rural areas where the monthly average solar irradiation range is 3 ± 6 kW h/m^2 [5–11].

Solar energy is also the most abundant permanent energy resource on earth. The potential amount of solar energy is considerably greater than current worldwide energy demands [12]. In fact, the total annual solar radiation falling on the earth is more than 7500 times the world's total annual primary energy consumption of 450 EJ. The annual solar radiation reaching the earth's surface, approximately 3,400,000 EJ, is an order of magnitude greater than all the estimated (discovered and undiscovered) non-renewable energy resources, including fossil fuels and nuclear [13]. The increasing efficiency, lowering cost and minimal pollution also made solar energy one of the fastest growing renewable energy technologies in the world [14–16].

Since 1992, the World Bank has engaged in active promotion of the use of SHSs for rural electrification. By 2009, the World Bank Group has contributed US$790 million to off-grid solar home systems in 34 countries. The World Bank, together with the International Finance Corporation (IFC), the private lending arm of the World Bank Group, has become one of the largest sponsors of off-grid solar PV in the developing world, having supported the installation of over 1.4 million SHSs [17].

The World Bank's PV investment experience provided a broad base for understanding the challenges, successes and lessons learned and best-practices in solar PV diffusion in developing countries.[1] The purpose of this paper is to review and draw lessons from the experience of the World Bank's investment in rural PV market. Specifically, the review asks the following questions: what are the barriers to SHS adoption? What instruments have been used to overcome these barriers? Are these instruments effective? To what extent did the project trigger market transformation and contribute to carbon reduction? And what lessons can be learned for the way forward?

The rest of the paper proceeds in the following way. Section 2 is a brief review of related literature and the World Bank's SHS investment portfolio. Section 3 discusses barriers to PV market development and approaches adopted by the World Bank to address these barriers. Section 4 analyzes the impact of World Bank projects. Section 5 examines the lessons learned and Section 6 concludes the paper.

2. Literature review and the World Bank Group's SHS portfolio

2.1. Literature review

There have been multiple studies reviewing SHS dissemination practices. These studies aim to identify viable business, delivery and credit models for scaling-up off-grid PV industry. They also acknowledged the tremendous difficulties encountered in transforming rural PV markets.

An IFC study presented lessons learned from IFC investment in solar energy in emerging markets since the early 1990s [17]. The study concludes that most solar PV programs require subsidies to be viable; without some level of subsidy, solar PV in developing countries is often too expensive for the average rural household. The study also acknowledges that "the rural, off-grid, solar PV industry in emerging markets is a low-margin, high-risk business and that IFC has been unable to significantly transform markets and create sustainable business as originally anticipated."

During 1991–1999, Global Environment Facility (GEF) has provided grants of US$210 million towards the total cost of $1.4 billion of 23 off-grid solar PV projects in 20 countries. A review looking over the GEF investment experience finds that projects involving government intervention would result in greater penetration than purely private-sector models [18]. The review identifies the high transaction costs associated with marketing, service

[1] World Bank projects have supported a wide range of solar PV applications, including solar water pumps, solar lanterns, grid interactive solar power pack, isolated solar power station for villages, and grid connected solar PV and so on. For the purpose of this paper, the assessment is restricted to SHSs, and the terms SHS and solar PV are used interchangeably in the following.

and credit collections in rural areas as the main barrier to market development.

An evaluation of IFC/Global Environment Facility (GEF) renewable energy investment notes that the IFC/GEF's renewable energy portfolio has not achieved significant results and that the problems and challenges associated with small-scale renewables, in particular in the PV sector, are not unique to the IFC, and have in fact been issues for the GEF in general, leading to suggestions that the strategic direction of the GEF climate change portfolio being shifting away from solar PV projects.

Nearly half of GEF-sponsored projects were based in Africa. Another GEF study in 2004 attempts to review key results and lessons learned based upon experiences of UNDP-GEF projects in Africa [19]. The study identifies four PV delivery/business models and compared their strengths and weaknesses in terms of reaching customers, offering different product choices and customer education, and affordability.[2] The report concludes that each business model had distinct advantages, but all shared common difficulties in raising finance, dealing with theft, and keeping maintenance and management costs low. The review acknowledges that “a massive roll-out of PV systems into rural areas of Africa has not yet happened”; the delivery of solar PV systems in Africa presents “unresolved challenges for policy makers, program designers, investors and rural communities.”

Martinot, Cabraal and Mathur review 12 World Bank PV-based rural electrification projects during 1993–2000 [20]. The Bank's early experience points to the persistence of price and credit as major barriers. It also finds that marketing campaign can be extremely costly and time consuming in rural areas. The demonstration of a commercially sustainable business model is recognized as key to achieving project replication and scaling-up.

Miller [21] assesses how solar energy can be harnessed on a large scale using market approaches. The study emphasizes the role of entrepreneurs in promoting technological change not just through the systems they sold, but through the example they set to both new market entrants and policy makers that forged new markets and inspired new policies.

Bhattacharyya [22] provides a systematic review of the financing needs, potential financial flows, challenges, and options for financing off-grid electrification. The review highlights that the challenge to financing energy access remains a major global issue. Governments would have to commit not only funds but also create an enabling environment for private business, micro-finance organizations, and management and implementation of energy access activities in a timely and orderly manner. Removing barriers to investment and business promotion, and supporting innovative approaches through collaboration, learning from others and experience sharing will be very essential.

Chaureyl and Kandpal [23] review experiences from PV-based rural electrification and technology demonstration programs in terms of barriers and challenges in marketing and dissemination, institutional and financing approaches, productive and economic applications, as well as its techno-economic aspects. The review points out that some of the earlier World Bank/GEF/IFC projects on SHSs had highlighted the challenges being associated with sustainability and replicability of business models, development of regulatory mechanisms for energy subsidies and incentives, and integration of rural electrification policy with the dissemination of SHS.

Pode [24] reviews various mechanisms adopted to finance SHSs at the grass-root level in different regions in the world. The review concludes that transparent documentation on cost, affordable tariffs and subsidy components, no political motivation in solar energy program, continuous monitoring and evaluation procedures, maintenance and emphasis on responsive after sales services are important ingredients for the success of the SHS lighting program for poor.

2.2. Overview of the World Bank Group's SHS portfolio

In 1992,[3] the World Bank approved its first project that aimed to promoting SHSs (India Renewable Resources Development Project) for rural electrification. By 2009, 45 solar PV projects in 34 countries have entered the pipeline, including 41 Bank Projects and 4 IFC investments. The majority of the Bank-supported SHS projects are part of larger rural energy projects or multi-sector projects. The Indonesian Solar Home System Project was the only stand-alone project that solely focused on disseminating SHSs. All projects except the Bolivia Decentralized Energy for Rural Transformation Project were jointly financed by the World Bank and GEF. The GEF share is in the order of 20 to 25 percent. Table 1 shows World Bank projects with off-grid SHS components between 1992 and 2009.

These programs led to more than $7.7 billion investment, among which $1.3 billion or 17 percent is supported by World Bank loan and GEF grant. Most of the project cofinancing was mobilized by the private sector and client funding. Project size ranged from US$1 million to US$144.9 million, with an average size of US$25.4 million. By 2009, 64 peak megawatt (MWp) of capacity of SHSs had been installed in 1.43 million households and institutions.

SHSs have been promoted in all World Bank regions, except Eastern Europe and Central Asia. The East Asia and Pacific region has had by far the largest amount of investment, totaling about US $287.1 million, or 38% of the portfolio. Africa is the second largest recipient of World Bank support, with total investment of over US $215.9 million. South Asia and Latin America and the Caribbean regions have received US$155.3 million and US$92.9 million investment, respectively. The Middle East and North Africa is represented only by a US$1 million project in Morocco, despite the region's solar resource.

To update the evaluation of the World Bank's earlier experience with the solar market, this paper draws on a review of 12 recently closed World Bank solar PV projects that are well-documented and have an installation target greater than 10,000 SHSs. The list of projects is shown in Table 2. The review was conducted through desk review of project-related documents, interviews and discussions with World Bank task team leaders, and a field visit to China.

3. Project design – barriers and interventions

All World Bank projects adopted market-based approaches that rely on private companies to market, sell, and install SHSs and provide after-sale services. By actively engaging the private sector, the Bank projects promoted a critical shift from a largely state-administered approach in the developing countries. Within the portfolio, project design involved both investment and technical

[2] The four models are: (1) “commercially-led model” which typically operates on the basis of cash sales; (2) “multi-stakeholder programmatic model” under which a project management unit is engaged in bulk procurement and is charged with reaching rural customers, perhaps also extending consumer credit to them; (3) the third delivery model is “utility model” which is typically operated on a fee-for-service basis; and (4) the fourth type is “grant-based model” which applies typically to institutions.

[3] This portfolio review is based on World Bank Clean Energy Investment Framework (CIEF) database and the IEG portfolio review of the World Bank Renewable Energy and Energy Efficiency Projects.

Table 1
World Bank Projects with off-grid solar home system components (1992–2009).
Sources: Martinot et al. (2001), Independent Evaluation Group "low-carbon" project databaseNote: Financing costs of projects approved before 2000 reflect the costs of the entire project. Financing costs of projects approved after 2000 reflect the cost of the components related to SHS investments.

Project name	Approval dates and status	Bank/GEF funding (US million dollars)	SHS component description
India Renewable Resources Development Project	1993/Closed	450	2.145 MWp of PV in various applications (commercial, water pumping and SHS)
Indonesia Solar Home Systems Project	1996/Closed	118	8054 SHS sold and installed by private dealers/entrepreneurs
Sri Lanka Energy Services Delivery Project	1997/Closed	29.9	21,000 SHS sold and installed
Lao PDR Southern Provinces Rural Electrification Project	1998/Closed	2.2	20 solar battery charging stations by national utility and village electricity associations as demonstrations
Argentina Renewable Energy in Rural Markets Project	1999/Closed	121	26,061 SHS in households through regulated energy-service concessions
Cape Verde Energy and Water Sector Reform and Development	1999/Closed	48	4000 SHS in households through regulated energy-service concessions
China Renewable Energy Promotion Project	1999/Closed	444	10 MWp of SHS and PV-wind hybrid systems installed through private dealers
Benin Off-grid Electrification	1998/Closed	5.7	5000 SHS through regulated energy-service concessions
Togo Off-grid Electrification	1998/Closed	5.7	5000 SHS through regulated energy-service concessions
Ethiopia Energy Access Project	2002/Closed	46.25	Install 6000 off-grid SHSs.
Guinea Decentralized Rural Electrification	2002/Closed	5.5	Off-grid solar/renewable energy based electrification project benefiting nearly 20,000 households in more than 75 villages
Bangladesh Rural Electrification & Renewable Energy Development	2002/Closed	25.34	1,231,720 SHSs installed
Sri Lanka Renewable Energy for Rural Economic Development	2002/Closed	28.3	21,000 SHSs installed
Uganda Energy for Rural Transformation	2002/Closed	9.8	1.292 MWp of offgrid PV systems installed
China Renewable Energy Development	2003/Closed	155.9	400,000 SHSs installed
Nicaragua Off-grid Rural Electrification	2003/Closed	13.03	1 MW of decentralized offgrid system established
Bolivia Decentralized Energy, ICT for Rural Transformation	2003/Closed	13.93	Installed 10,174 SHSs
Cambodia Renewable Energy Development	2003/Closed	4.24	12,000 households served with SHSs.
Mozambique Energy Reform and Access Project	2003/Closed	7.21	Install 300 KWp off-grid solar PV which would serve 2500 households
Mali Household Energy and Universal Access Project	2003/Closed	21.92	40,000 homes, 1080 enterprises, public institutions, trading centers and communities gain access to modern energy
Philippines Rural Power Project	2004/Closed	11.9	Install 0.4 MWp of PV capacity which would serve about 10,000 consumers
Senegal Electricity Service for Rural Areas	2005/Closed	18	Install 12,000 SHSs of 20WP and 8000 SHSs of 50Wp
Honduras Rural Infrastructure Project	2005/Under implementation	9.4	Install 274 kW SHSs to serve at least 4000 dispersed households, business and public facilities
Nigeria National Energy Development Project	2005/Closed	9.1	3000 rural and 4000 peri-urban customers provided with renewable energy based electricity service
Papua New Guinea Teacher's Solar Lighting Project	2005/Closed	0.99	Install 2500 household solar kits and build industry capacity to allow rapid scale-up of solar market
Honduras Rural Electrification	2005/Closed	2.35	4000 dispersed households, businesses and public facilities obtain sustainable electricity access provided with SHSs
Lao PDR Rural Electrification Project Phase I	2006/Closed	1.75	Provide off-grid electricity service to 200 villages and 10,000 households
Peru Rural Electrification	2006/Closed	44.225	Install 15 MW renewable generating capacity to serve 20,000 households
Pacific Islands Sustainable Energy Finance Project	2007/Under implementation	9.48	Install off-grid solar PV of 866,500 kw to serve 21,000 households
Mongolia Renewable Energy and Rural Access	2007/Closed	9.76	67,224 SHSs installed in off-gird soums centers
Sri Lanka Renewable Energy Additional Financing	2007/Closed	11.1	Provide direct electricity access to an additional 60,000 households and 500 rural SMEs and public institutions directly through off-grid systems
Bolivia Decentralized Electricity for Universal Access	2007/Closed	5.175	Installation of 7000 SHS for dispersed rural households, schools, clinics and micro and small enterprises. Distribution of an estimated 2000 "Pico PV" systems for lighting and basic ICT services for the poorest households (below 20Wp)
Tanzania Energy Development and Access Expansion	2007/Under implementation	20.5	15,000 new rural households and business connections to electricity services through new off-grid models.
Bangladesh IDCOL SHS project	2007/Under implementation	2.419	226,700 units of SHS with capacities between 30 and 120 watts, to be installed by 2015 in off-grid areas of Bangladesh
Ghana Energy Development and Access	2007/Under implementation	3.11	Supply solar PV lanterns and SHSs for lighting in remote rural areas for 10,000 households
Burkina Faso Energy Access project	2007/Under implementation	6.7	2000 solar kits and about 100 institutional systems to be installed.
Bangladesh Grameen Shakti Solar Homes Project	2007/Under implementation	4.696	The project activity will install 198,978 units of solar home systems, with the capacity of 65 watts, by 2015 in regions in rural Bangladesh that are not connected to the electricity grid.

Table 1 (*continued*)

Project name	Approval dates and status	Bank/GEF funding (US million dollars)	SHS component description
Zambia Increased Access to Electricity	2008/Under implementation	11.5	Install 410 kWp solar PV systems to serve 250 rural schools and clinics and 10,000 households
Mexico Integrated Energy Services Project	2008/Under implementation	7.02	35,000 households are expected to gain electricity via SHSs with a total installation of 3400 kw
Ethiopia Electricity Access Expansion Project Phase II	2008/Under implementation	8.31	Installation of 200 solar PV system in remote, off-grid areas for social services (schools and clinics) and provide technical assistance and capacity building

Table 2
Solar PV projects under evaluation.
Source: World Bank Project Appraisal Documents and Project Implementation and Completion Reports of the following listed projects.Note: Costs/financing are/is specific to solar component except Senegal Electricity Services of Rural Areas Project.

Project name	Solar component cost (US$ million)	Project dates	
		Initiation	Completion
Argentina Renewable Energy in the Rural Market (PERMER)	79.1	12/09/1999	12/31/2011
Bangladesh Rural Electrification & Renewable Energy Development (RERED)	25.34	12/31/2002	12/31/2012
Bolivia Decentralized Energy, ICT for Rural Transformation	13.93	12/18/2003	11/27/2009
China Renewable Energy Development (REDP)	155.9	12/12/2001	06/30/2008
India Renewable Resources Development	23.8	04/06/1993	12/31/2001
Indonesia Solar Home Systems	16.8	07/06/1996	12/31/2003
Mongolia Renewable Energy and Rural Access	9.76	05/04/2007	12/31/2011
Philippines Rural Power (RPP)	11.9	05/06/2004	12/31/2012
Senegal Electricity Services for Rural Areas	18	06/30/2005	12/31/2012
Sri Lanka Energy Services Delivery (ESD)	9.2	2/20/1997	12/31/2002
Sri Lanka Renewable Energy for Rural Economic Development (RERED)	28.3	10/07/2002	06/30/2011
Uganda Energy for Rural Transformation (ERT)	9.8	07/30/2002	02/28/2009

assistance components to address a series of interrelated barriers to PV market development.

3.1. Barriers

3.1.1. Cost and financing for consumers

The cost of a 20 Wp system ranged from US$150 to $490 in the portfolio. Although the operating cost per lumen (unit of illumination) is theoretically less than that of a kerosene lamp, the upfront cost is prohibitive for rural poor. Because of the perceived high risks of rural financing, financial institutions were either unwilling to finance rural electrification or had charged high interest rates, making financing for PV purchase unaffordable.

3.1.2. Financing for manufactures and dealers

SHSs are assembled by small manufacturers that have limited capabilities in financial management and business model design. It was difficult for these companies to obtain bank loans because of their informal record keeping and accounting.

3.1.3. Biased pricing policies

High import tariff on solar modules and government subsidies to competing fuels were the most common policy barriers. In Sri Lanka, for instance, solar PV modules were initially subject to 35 percent import duties. In Indonesia, when the price of PV systems increased by 400 percent due to depreciation of currency, the imported price of kerosene and diesel only increased by 40 percent and 58 percent, respectively, thanks to government subsidies. In Uganda, solar purchases were subject to extra duties aimed at protecting a local battery company.

3.1.4. Anticipation of grid connection

Households much prefer the convenience and reliability of grid connections and will not invest large sums in SHS if connection to the grid is imminent. Ambiguous plans or too-optimistic promises on grid integration discouraged demand for SHS. In general, rural electrification was often not integrated into national energy policy. The absence of regulatory guidance created uncertainties that discouraged both demand and supply.

3.1.5. Poor quality

Companies operating in rural PV markets were often small start-ups, with limited technical and business experience. Insufficient knowledge with regard to proper sizing, installation, operation and maintenance, troubleshooting, and the lack of PV manufacturing standards resulted in poor-quality products and service. Uncertainty about SHS quality and reliability dampens consumer demand for these expensive investments.

3.1.6. Information barrier

Although PV systems provide lighting far superior to kerosene and other conventional fuels, the lack of awareness of the benefits of a PV system and confidence of the reliability of the system limited consumers' willingness to pay. The lack of knowledge on the potential market size and characteristics, and the potential return on investment also constrained the participation of private investors and financiers.

3.1.7. Geographic barriers

Off-grid populations tend to be in areas of low population density with difficult terrain. For example, in Bolivia, the user density is under 1 household per square kilometer; while in Mongolia, the population density was 1.8 persons per square

kilometer. Existing PV companies find it costly to develop sales and marketing infrastructure to serve these populations.

Many of the above barriers were interlocking. On one hand, information, technical and geographic barriers all contributed to the financing barrier; on the other hand, lack of provision of affordable rural credits makes the PV system even more costly. Without investment or policy intervention, PV markets would therefore be struck at a low-sales-volume and high-price equilibrium.

3.2. Interventions

The World Bank projects have adopted three different delivery models and deployed a variety of instruments to break barriers and to catalyze the development of the PV market. In this section, we review the choice of delivery models and interventions, including subsidies, consumer credits, investor financing, and technical assistance.

3.2.1. Delivery models

Three different delivery models have been adopted by the World Bank. They are dealer-sales model, fee-for-service model, and a hybrid of the two. In a dealer-sales model, dealers purchase systems or components from manufacturers and sell them directly to households, usually as installed systems. The household then owns and maintains the system. Dealers are responsible for after-sale service and may provide flexible payment or credit mechanisms to make systems more affordable. In a fee-for-service model, the consumer is provided with electricity service through an energy service company. The company owns the SHS, charges a monthly fee to the household, and is responsible for maintenance and providing replacement parts over the life of the service contract. The energy service company can operate as a monopoly concession regulated by government to serve specific geographic regions (mostly in Latin American countries where there is a well-established system of concession areas for various services), or it can operate in an open market.

The dealer-sales model was employed in China, Indonesia, India, and Philippines. Dealers can participate in the project based on eligibility criteria, such as existing business competence, sales/service infrastructure in related rural markets, and credit agreement with participating banks. The fee-for-service model was applied in Argentina and Senegal, where franchise rights to rural-service territories were granted to concessionaires. In Argentina, the winning bidder for a concession area was the firm that required the lowest subsidy to provide households and public centers service in the concession areas. In Senegal, the total subsidy was predetermined; the firm that offered to serve the highest total number of individual users won the bid. In Bangladesh, Sri Lanka, Uganda and Mongolia, both dealer sale and fee-for-service models were tested, where, under the fee-for-service model, energy service companies were subject to market competition rather than operating as regulated monopolies.

The model used in Bolivia can be viewed as a hybrid of the dealer-sales and fee-for-service models. Known as the Medium Term Service Contract, this model adds mandatory local-market development and 2–5 years of operation-and-maintenance services to the dealer-model requirements for participating companies. The model can also be considered a revision of the traditional concession scheme, whereby the exclusivity term is reduced to only 2–5 years and opened to a broader menu of ownership options. The concession was awarded based on minimum subsidies requirement.

Table 3
SHS subsidy levels in selected World Bank Projects.
Sources: World Bank Project Appraisal Documents and Project Implementation and Completion Reports of the following listed projects.

Country	Project	PV System size (Wp)	Approx. subsidy range (% of cost)
Argentina	PERMER	50–100	Up to 50
Bangladesh	RERED	20–70	12
China	REDP	10–500	10–15
Sri Lanka	RERED	10–60	10–25
Philippines	RPP	20–100	20–60

3.2.2. Subsidies

Regardless of delivery mechanism chosen, most project employed subsidies.[4] Under a dealer-sales model, subsidies were issued to dealers either on a per unit or per Wp basis; dealers were qualified for subsidies only if their product and service quality meet the project's standards.

Under a fee-for-service model, monthly subsidies were provided to low income and rural consumers to reduce their operating costs, as in Argentina, or to winning concessionaires to cover capital expenditures, as in Senegal and Bolivia. Table 3 shows the approximate subsidy range as a percentage of system costs of selected projects where subsidies information is available.

3.2.3. Consumer credits

Consumer credits were provided via three primary mechanisms: dealer extended credit, credit through local banks, and credit through microfinance institutions. Experience in Sri Lanka and Bangladesh suggests that microfinance providers, who work closely with solar companies, were generally more suited for financing rural renewable energy than commercial banks or dealers of SHSs.

In the original design of ESD in Sri Lanka, the SHS vendors and commercial banks were expected to perform the function of a financial intermediary. However, it was proved early in the project that given the additional costs, expertise and risks involved, both were ill-suited for the financing needs of the highly decentralized, door-to-door distribution of off-grid SHSs. Midway through the project, the project adopted a microfinance model in partnership with a key nongovernmental organization (NGO), the Sarvodaya Economic Enterprise Development Services (SEEDS) to provide consumer credits. With the involvement of SEEDS, the solar market took off dramatically: system vendors were relieved of the consumer financing burden, thus allowing them to concentrate on marketing, installation and servicing of solar systems. Many of the retailers achieved double digits growth rates since the participation of SEEDs.

The RERED project in Bangladesh also relied on well-functioning microfinance institutions to provide rural credits to purchase SHSs. Under a credit program, the Infrastructure Development Company Ltd. (IDCOL), a financing institution created by the government with the help of the World Bank, made sub-loans to participating NGOs and microfinance institutions (MFIs) for refinancing up to 80 percent of loans made to consumers. The program was led by NGO/MFIs who were responsible for identifying potential consumers and making consumer loans. Since 2003,

[4] There are at least three rationales for using the subsidies mechanism: (1) to achieve social equity, that is the need for remote or poor dwellers to achieve a level of parity with households in concentrated areas that benefit from subsidized grid-extension infrastructure; (2) to improve economies of scale by stimulating demand and supply, therefore reducing PV systems costs; and (3) to improve product and service quality. Projects often used "carrots and sticks" principle: companies that met project standards were eligible for subsidies; companies whose product quality fell short of standards were subject to financial penalty.

15 NGOs and MFIs, such as Grameen Shakti, Brac Foundation, Srijani Cost Trust and so on had formed alliances with SHS suppliers for the installation and servicing of solar systems.

In India, the participation of cooperatives or micro/rural financing entities was also recognized as a key to address rural credit risks and to make the system accessible to rural/poor consumers. This experience suggests that microfinance institutions with an established rural network and community-based approach, or NGOs with the potential to expand into credit activities, could overcome, to some extent, the geographic barrier to reach adequate numbers of lower income households.

3.2.4. *Investor financing*

Financing instruments for private investors include partial loan guarantees and special purpose funding. For example, in Uganda under the Energy for Rural Transformation (ERT) Project, a Credit Support Facility was developed to facilitate long-term commercial debt finance. Furthermore, the facility provided credit enhancements so that some of the risks associated with rural electrification and renewable energy were shared between the Government and the financial sectors.

3.2.5. *Technical assistance*

Bank projects provided a broad range of technical assistance to increase the awareness and knowledge of PV technology, and to improve PV companies' technical and business capabilities. The Bank's technical assistance includes public information campaign, small-scale demonstration in highly visible locations, training for technicians, market monitoring and surveys, stakeholder workshops, and so on.

Technical assistance was provided either in the form of a predetermined package, or through a bottom-up approach which allows PV companies to identify weaknesses and opportunities to improve business and market development. The latter approach was undertaken by the China REDP, the Philippines RPP and the Uganda ERT.[5]

Another important aspect of project technical assistance was the introduction and/or upgrading of technical specifications and service standards, and the development of domestic testing and certification capacities. Subsidies were often linked to these standards – investors were qualified for subsidies only when they met the technical standards – and proved to be effective in situations where consumer perception of and feedback on quality was limited.

4. Project outcomes

All projects in the evaluation portfolio had the development objectives of (i) increasing access to electricity in rural areas in an environmentally sustainable manner and (ii) facilitating greater participation by the private sector in advancing the commercialization of photovoltaic technology. In addition, 4 of the 12 projects specifically spelled out the goal of fostering economic growth or improving the delivery of social services such as health and education through the provision of electricity services. The global environmental objective of the solar photovoltaic projects was to remove barriers to the adoption of emissions-reducing energy technologies.

Table 4
Installed solar PV systems.
Sources: World Bank Project Appraisal Documents and Project Implementation and Completion Reports of the following listed projects. Note: NA indicates data are not available.

Projects	Total number/capacity of installed SHS		
	Targets	Actual	Actual/targets (%)
Argentina	22,543	26,061	116
Bangladesh	994,000	1,231,720	124
Bolivia	15,000	10,174	68
China	350,000	400,000	114
India	2.5–3 (MWp)	2.145 (MWp)	86
Indonesia SHS	70,000	8054	12
Mongolia	50,000	67,224	134
Philippines	10,000	19,525	195
Senegal	NA	1503	NA
Sri Lanka ESD	15,000	21,000	140
Sri Lanka RERED	136,185	138,480	102
Uganda	0.32 (MWp)	1.292 (MWp)	404

4.1. *Increased access to electricity in rural areas*

Table 4 shows the SHS installation outcome of projects in the sample. With the exception of Indonesia – where the 1997 macroeconomic crisis crippled consumer demand – most of the projects performed well against targets. In all other places installation of SHS at project closure has significantly surpassed original targets. As a result, a great number of households in isolated rural areas have gained access to electricity. For example, the SHS component under the China REDP project helped more than 2 million people.

4.2. *Facilitate private participation and commercialization of PV technology*

The projects contributed to the creation of commercially-viable PV markets. For example, in China, the SHS companies had doubled their employment numbers, increased sales and service outlets from 266 to 721. The rural sales revenue expanded 363% from RMB 48.7 million yuan to RMB 225.1 million yuan. The PV companies also upgraded their financial management by computerizing their accounting systems and introducing standardized documentation and controls so as to comply with the subsidies eligibility requirements of the project.

In India, commercial market development was advanced as evidenced by: (a) a large private sector-led manufacturing base was developed; Indian became the fifth largest PV producer in the world with an annual output of 20 MWp in 2000, (b) a competitive market place was established, (c) retail sales and service networks were developed, and (d) emerging participation of financial intermediaries.

In Sri Lanka where there were only 2 and 3 small operations selling roughly 20–30 systems per month in 1998, the average sales reached about 850 systems per month in 2002. By 2009, there were 14 accredited companies marketing SHS and more than 100 sales and service outlets throughout the country. More importantly, because of the demonstration of the project, lending institutions outside the projects started extending credits to SHSs, which brought greater customer choice and competition in the financial sector.

[5] A Market Development Support Facility (MDSF) was introduced in China and Philippine, and a Private Sector Foundation in Uganda was developed to provide cost-shared grants to PV companies to assist them in improving business and technical capabilities. Each company could apply and disburse the funds based on their own assessment of their shortcomings and needs. In addition, the cost-shared scheme can also leverage additional private investments. In China, the MDSF typically only covered 42% of the cost for activities on advertisement, financial management improvement, product certification and market surveys.

Table 5
Average PV system costs before and after the project ($/Wp).
Sources: World Bank Project Appraisal Documents and Project Implementation and Completion Reports of the following listed projects, China REDP Project Performance Assessment Report, Sri Lanka RERED statistics and reports. (http://www.energyservices.lk/statistics/index.htm).

	Before project	After project	% of change
China REDP	16	9	−43
India RRDP	16.5–25.8	4.8–14.2	−33
Sri Lanka ESD	11	10	−1
Uganda ERT	20	12–17	−15

4.3. Reduce greenhouse gas emissions

Overall, the projects have not made a significant contribution to the reduction of GHG emissions because of low capacity factors and low usage of energy by poor rural people. In India, the avoided carbon emissions were estimated to be 94,000 tons over the lifetime of the PV subproject. In China, a rough extrapolation implies total CO_2 reductions in the order of 7000 tons per year.[6]

4.4. Removing barriers including high implementation costs

Another important goal of these projects was to sustainably reduce the price of SHS and thereby increase access. In general, closed projects for which data are available all observed reduction in the cost of PV systems (Table 5). Under China REDP, PV system costs declined from about US$16/Wp to US$9/Wp. In Uganda, the PV system cost declined from US$20/Wp to US$12–17/Wp by the end of 2008. In India, the unit costs of PV systems reduced from US $16.5–$25.8/Wp to $4.8–$14.2/Wp over the course of the project.[7] These declines probably reflect increased domestic competition. The programs are too small to have affected the global market for solar modules, where increased European demand drove down prices over the decade.

4.5. Forster economic growth and/or improve the delivery of social services

Evidence on these projects' poverty reduction impacts is spotty because of the lack of monitoring. In India, some traders reported a 50 percent increase in net income by using solar instead of kerosene lighting; income of some rural households increased by about 15–30 percent because of increased home industry output. SHSs also allowed longer study hours for children under better lighting conditions. In China, a 2007 end-user survey covering 1203 households in 6 villages reported that 95 percent of SHS users claimed that the use of a PV system increased their incomes; 15 percent claimed that the increase was significant.

4.6. Economic efficiency

In Bolivia, Indonesia, the Philippines, and Sri Lanka, the economic rates of return for investment in SHSs were estimated in the range of 30–90 percent. For China, the solar project achieved a phenomenal 115 percent economic rate of return. These estimates depend on technical assumptions about consumers' benefit from lighting and may not be comparable between projects. These very high numbers are consistent with studies that show huge gains to rural electrification [25].

5. Lessons Learned

The Bank experience in promoting SHSs in the past decade point to the following lessons:

5.1. Microfinance was a critical input for success in several projects

Two factors accounted for the success of the projects in Bangladesh, Sri Lanka, and China. Consumer finance was crucial. In Sri Lanka's energy services delivery project, the SHS vendors and commercial banks were expected to provide financing but proved ill-suited to deal with collecting payments from the highly decentralized off-grid customers, and the project languished. The project took off after shifting to a microfinance model.

The Bangladesh RERED project also relied on well-functioning microfinance institutions. China's REDP project achieved success despite lack of financing arrangements in provinces where many clients were yak herders who could self-finance a system through sales of their animals.

5.2. Quality-contingent output-based producer subsidies were important

The second factor was the use of output-based producer subsidies. The development of the Chinese industry is noteworthy, as it illustrates an effective set of mechanisms to promote manufacturing quality and capabilities. Demand-driven grants enabled companies to improve their technologies and financial management systems. Technology-neutral subsidies—contingent on achieving quality standards—served as an incentive to improve quality, provided small firms with capital for expansion, and were to some degree passed on to consumers, boosting demand.

As a result, the SHS companies doubled their employment, tripled sales and service outlets from 266 to 721, and more than tripled sales. The inland city of Xining emerged as a manufacturing center and began to export products.

5.3. Initial market development and capacity building.

Experiences of Bank projects in China, Indonesia, India, Sri Lanka, and Uganda indicates that the development of PV projects usually proceeded slowly in the first few years but increased significantly once start-up problems were solved and the marketing and sales infrastructure and the institutional capacity was built. For example, in the case of India, much of the first four years was spent on capacity building and working with perspective investors. It was only in the fifth year that the pace accelerated. After that acceleration, scaling up was much easier at a lower cost. Projects in Sri Lanka had the similar development trajectory as shown in Fig. 1. From 1997 until 1999, the ESD project delivered only 500 SHSs. But in 2000 alone, the sales and installation reached to 1891, due to the rapid roll-out of its market infrastructure. In 2001, the number of systems sold jumped to 10,742. It is therefore important to have realistic expectations on the pace of the market development and take time to build the policy, institutional and financing framework.

[6] The estimation was made based on a kerosene usage survey in 2007 of 1203 households in four counties in China. Data on the volume of energy consumption across all fuels before and after the purchasing of a PV system were collected. Carbon emissions reduction was estimated based on the reduction of kerosene use.

[7] It should also be noted that it is difficult to compare cost across countries, some sources included cost of installation, and others only hardware. The difference in cost of PV systems may also relate to differences in duties and tax structures.

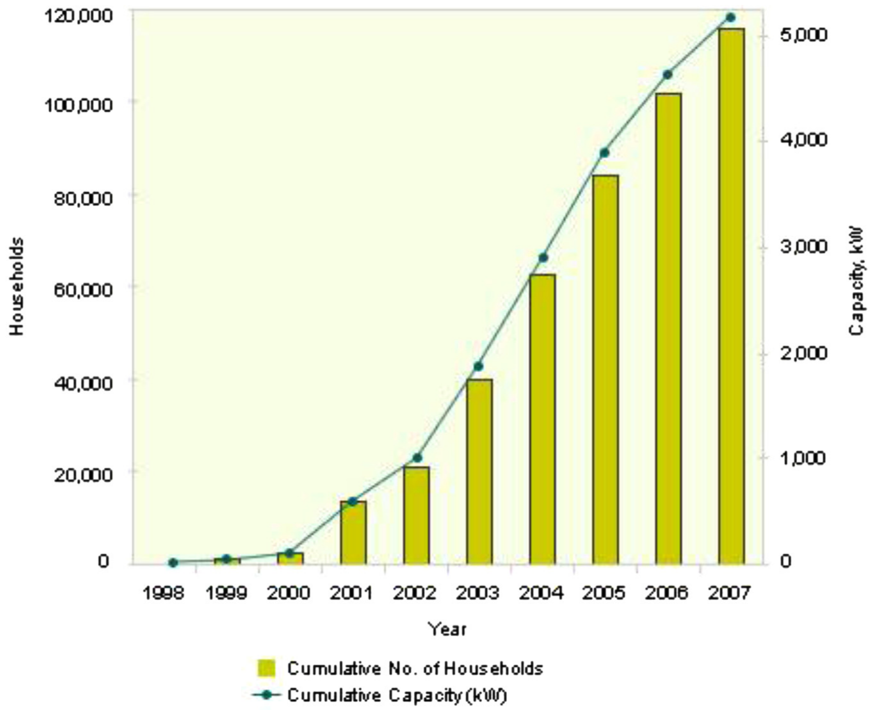

Fig. 1. SHS installed under ESD (1997–2002) and RERED (2003–2007).
Projects source: Sri Lanka RERED Statistics and Reports (http://www.energyservices.lk/statistics/index.htm),

5.4. Local implementing agency and business cluster

Any large scale dissemination of SHS units has involved a competent local implementing agency, such as the project management office in China, and the administrative unit in Sir Lanka. These local agencies started with the advantage of being familiar with local conditions and procedures. They not only performed accounting, disbursement and verification, and quality inspection on a timely and comprehensive basis, they also served as a local champion to advocate solar PV technology and mobilized the interests and participation of new investors.

After the closure of Bank projects, industry associations took over the role of implementing agencies in promoting SHS business activities, providing advices to SHS dealers and sharing supply chain information. These business associations have also been essential for PV market development, especially when the PV investors were relatively small and less experienced.

5.5. Coordination between government and donor programs

The lack of coordination between World Bank Projects and parallel government programs and other donor sponsored projects had undermined the efficiency of project delivery. For example, under those parallel competing projects, local governments or donors procure SHS units which are then provided to households on a free or highly subsidized basis. Such “dole outs” not only encouraged “double dipping” by participating PV companies (who can claim subsidies for the same unit under different programs) but also undermined the market based approach promoted by the Bank project. Indeed, in China, India and Philippine the provision of subsidized systems had undercut more market-oriented sales.

6. Conclusions

In remote areas with low population densities, it can be cheaper to provide decentralized renewable power through home systems or mini-grids than to extend the main electric grid. This has raised hopes of fighting both climate change and poverty with a single instrument, or using climate finance to promote rural access. Those hopes are manifested in the large investments in solar home PV systems, the off-grid technology with which the World Bank Group has the longest record. During 1992–2009, the World Bank Group has contributed US$790 million to promote SHSs in 34 developing countries, the largest single area of off-grid renewable energy investment.

This paper examines the effectiveness and the efficiency of the World Bank projects completed during the second decade of Bank's intervention. The analysis finds that the World Bank efforts, using quality-contingent producer subsidies and relying on microfinance for consumers, have been successful in promoting the market penetration of SHSs. World Bank support has also helped develop manufacturing capacity for SHSs and reduce local prices in China, India, Sri Lanka, and Uganda. These projects can have economic rates of return of 30–90 percent.

However, the solar PV projects supported by the World Bank loan were generally small in scale and had achieved little impact on GHG emissions reduction. To make a significant impact on GHG mitigation World Bank's resources need to be leveraged as far as possible in order to meet the capital needs of providing low-carbon energy to developing countries. Future investments could focus on scaling up investment on technical, financial and institutional innovations that have potentially high returns, using piloting and demonstration to adapt and diffuse these technologies to wider audiences. For example, providing quality-contingent subsidies for manufacturers has proved to be a useful instrument for boosting competition and quality, and promoting market penetration. The vision is to provide a pipeline of development solutions that can be pursued on a large scale by the World Bank and other funders and private investors.

Overall, the emerging evidence from the World Bank experience suggests that SHSs can leapfrog power grids at least for households with access to good microfinance services, even though in many places, markets are still reliant on subsidies. However, if solar modules

continue to get cheaper as the trend in recent years shows, the solar subsidy itself could be leapfrogged.

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